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Course
On
Laws of Thermodynamics

by
Prof. Suman Chakraborty
Department of Mechanical Engineering
Indian Institute of Technology Kharagpur

Lecture 19: Tutorial 5: Entropy and its Transport

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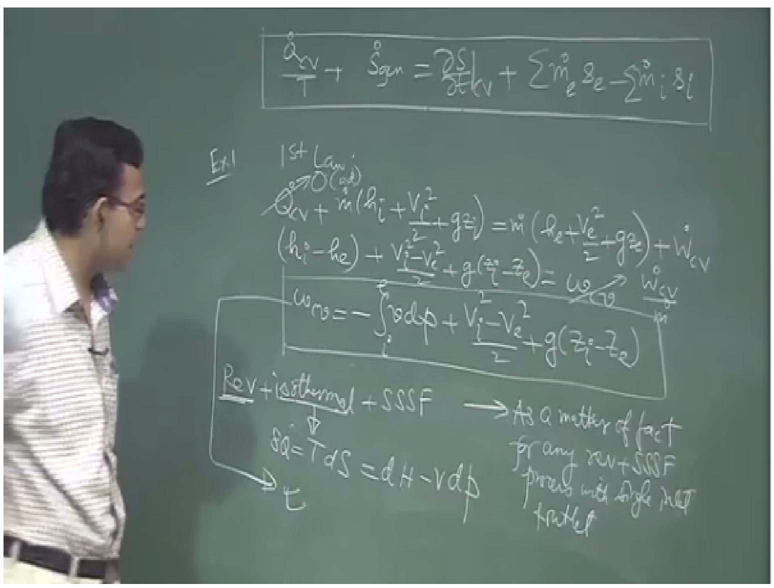

In the previous lecture we were discussing about the entropy transport in a flow process and we were talking about a typical example which is still there in the board that we are considering a reversible steady state, steady flow process with single inlet and outlet. So now we will consider a special case of this.

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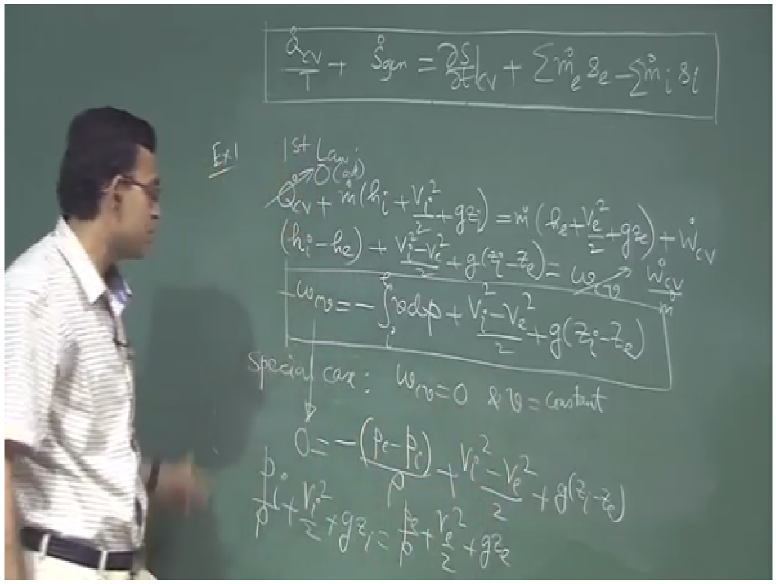

Wcv=0 and V=constant, so a special case when there is no work done and the specific volume remains constant, it is a constant density incompressible fluid. So in that case this equation will boil down to 0 is equal to now you can take V out of the integral, because it is a constant, so you can write –(Pe-Pi) V you can write as 1/ρ so +Vi^2-Ve^2/2+g(zi-ze). So you can write Pi/ρ+Vi^2/2+g(zi)=P/ρ+Ve^2/2+g(ze).

Amazingly, it looks very much like the Bernoulli's equation. But again illusively this is not the Bernoulli's equation, this looks like Bernoulli's equation, but this is actually a mechanical energy conservation equation. The Bernoulli's equation you apply between two points here you apply the stead state, steady flow energy equation between two sections, i and e are not two points, they are two sections and you are assuming that the properties like velocity, pressure are uniform over those sections.

Otherwise, you may have to give a correction factor to these which are known as kinetic energy correction factors in fluid mechanics. So I am trying to draw a perspective also, here you see we are bridging the inter linkage between fluid mechanics and thermodynamics. And you see that this looks like the Bernoulli's equation. And therefore, this can be interpreted as a mechanical energy conservation equation for a steady state, steady flow reversible steady state, steady flow process with single inlet and outlet with no work done and constant density fluid.

So these are the assumptions based on which this equation can be applied okay. With this little bit of background on entropy transport for non flow and flow processes let us try to work out some examples, some problems on entropy transport. So we will go to the tutorial problems chapter 4.

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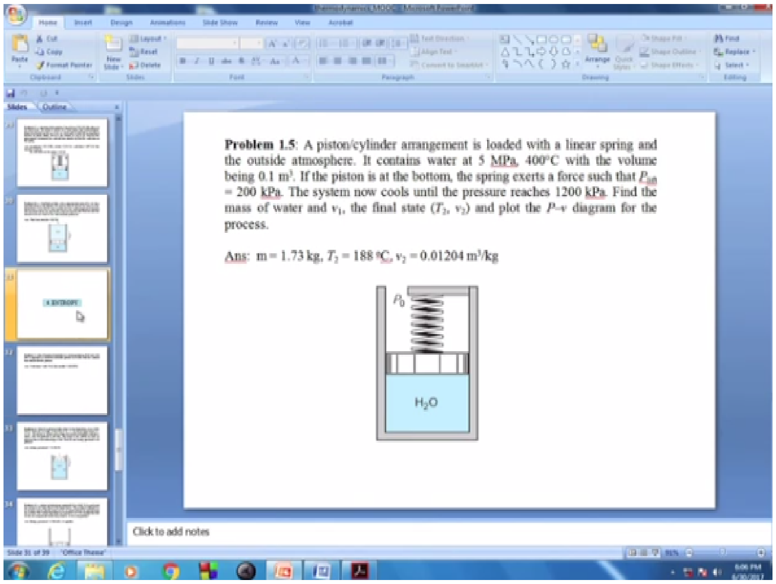

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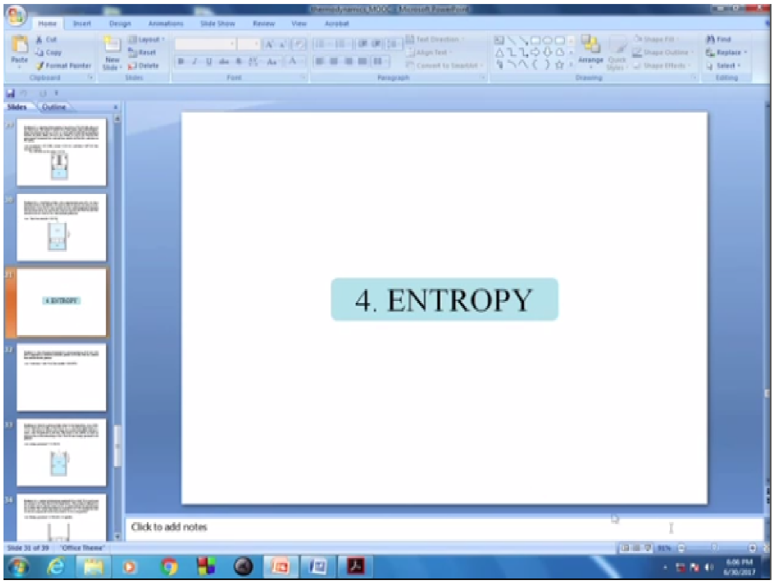

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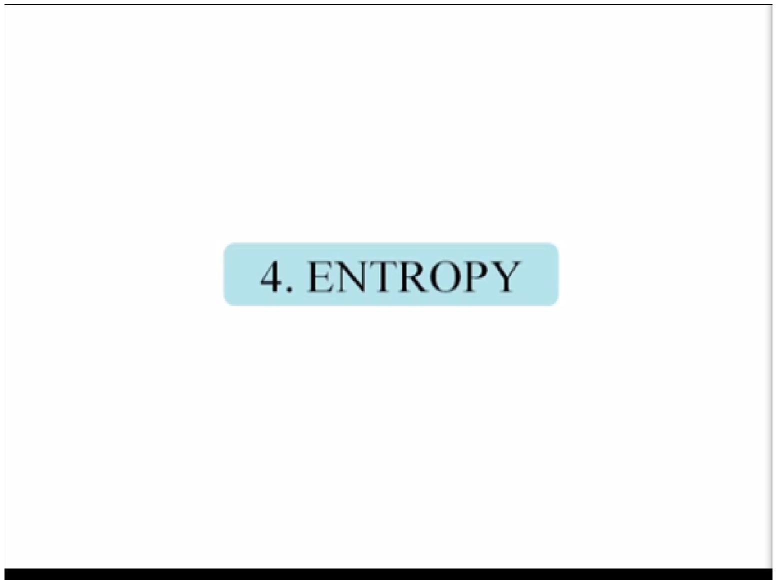

So we will start with the problem number 4.1.

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Problem 4.1: One kilogram of ammonia in a piston/cylinder at 50 °C and 1000 kPa is expanded in a reversible isothermal process to 100 kPa. Find the work and heat transfer for this process.

Ans: Work done = 363.75 kJ, Heat transfer = 396.967 kJ

So we have about 7 to 8 problems in this particular chapter. And what I plan to do is I planned to discuss about these problems in brief so that you know how to solve the problems instead of getting into the numbers, I give you the principle of solving the problems, the concept of solving the problems which you can use and work out the numbers. So the first example one look at this screenshot, 1kg of ammonia in a piston cylinder at 50° C and 1000 kilo Pascal is expanded in a reversible isothermal process to 100 kPa.

Find the work done and the heat transfer. So this kind of problem is a very illusive problem, because by looking into this it is given reversible isothermal process.

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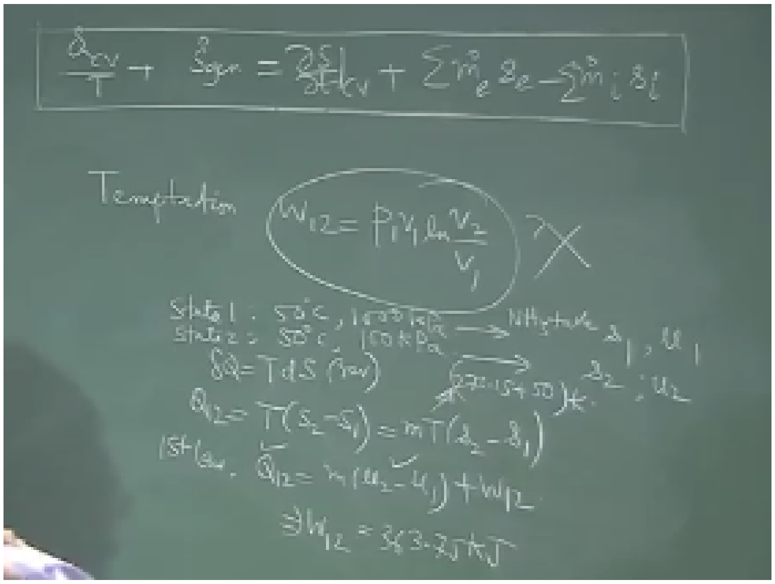

So you will have, let me write temptation, you will have a temptation of using the formula W12=P1V1LnV2/V1, this temptation come from school level approach of solving these problems where everything is ideal gas. Now whether this is correct or not let us evaluate this for this problem. So now let us look into the problem data.

So state 1 is given as 50^0C P1 as 1000kPa then how do you get state 2 because it is a revisable process you can write ∂Q = Tds this is for a reversible process so we can write that $Q1_2$ now it is an isothermal process so $T(s_2 - s_1)$ okay so what is the state 2 is till the temperature is 50^0C and the pressure is 100kPa so from the property table of ammonia you can get what is s1 and you can get what is s_2.

So $MT(s_2 - s_1)$ by the way entropy of if it is a two phase mixture entropy of a two phase mixture can be calculated by the same mixture rule which is used for calculating the specific volume internal energy enthalpy the same rule of mixtures can be used so this is the heat transfer this T is 273.15 + 50K, so now first law if you write $Q_{12} = m(u_2 - u_1)$, so from the table you can get u_1, u_2 also + W_{12} so if you substitute the heat transfer and $u_2 - u_1$ you will get w_{12} and the answer is 363.75kJ and clearly this is not P_1, v_1 l_n v_2/v_1 you can check from the data why because although this is isothermal process and reversible isothermal process for this process PV is not equal to constant because the ammonia considered in this problem may not be treatable as an ideal gas.

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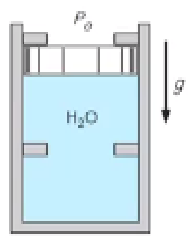
Problem 4.2: Water in a piston/cylinder, shown in the figure below, is at 1 MPa, 500°C. There are two stops, a lower one at V_{min} = 1 m^3 and an upper one at V_{max} = 3 m^3. The piston is loaded with a mass and outside atmosphere such that it floats when the pressure is 500 kPa. This setup is now cooled to 100°C by rejecting heat to the surroundings at 20°C. Find the total entropy generated in the process.

Ans: entropy generated = 19.45 kJ/K



This we must keep in mind, next problem we go to problem number 4.2, it is projected in the screen water in a piston cylinder is at 1MPa 500^{0}C there are two stops a lower one which is corresponding to a volume of 1m^3 and upper one which is corresponding to a volume of 3m^3 so the piston floats when the pressure is 500kPa initially the pressure is 1mPa so the heat as to be transferred from the system so that the pressure comes down from 1 MPa to 500kPa and then the piston will come down. And it will reject it is rejecting heat the surroundings find the total entropy generated in the process.

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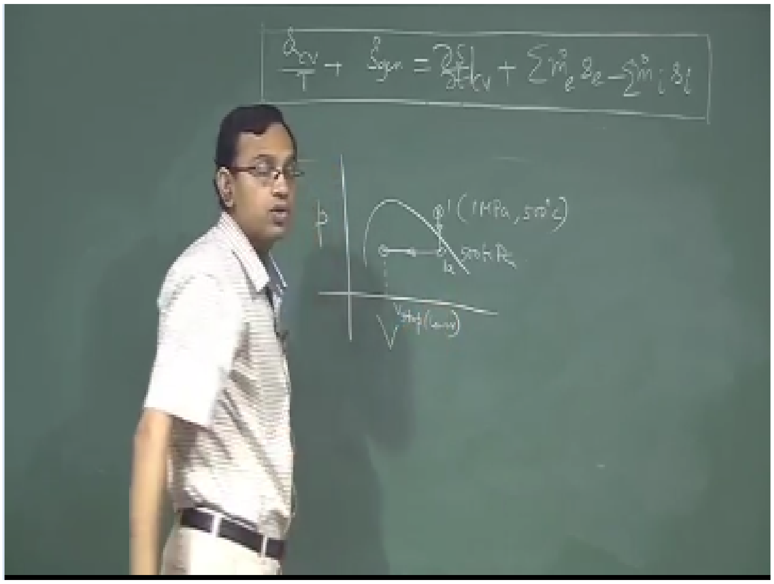

So let us try to work out this problem first we draw the PV diagram, so state 1 is super heated vapor which is 1MPa 500^{0}C the it comes down from 1MPa to 500kPa okay because the piston can float when only when the pressure comes down to 500kPa so from here to 500kPa let us say this is state 1A this is 500kPa then heat is rejected so it will come at a constant pressure it is volume will decrease. How much it will decrease it will decrease when it encounters the stops so it comes to the V stop the lower stop.

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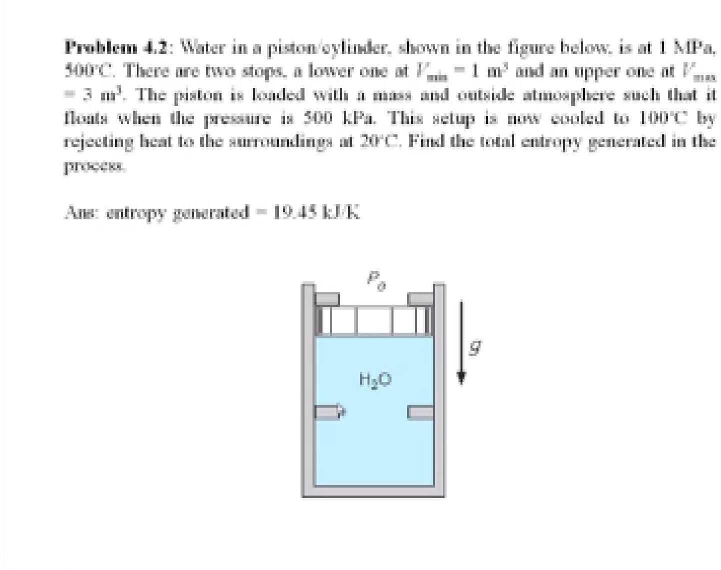

So if you look at this picture you will see there is a upper stop[and there is a lower stop so I am talking about this stop by calling V stop so this V stop is $1m^3$

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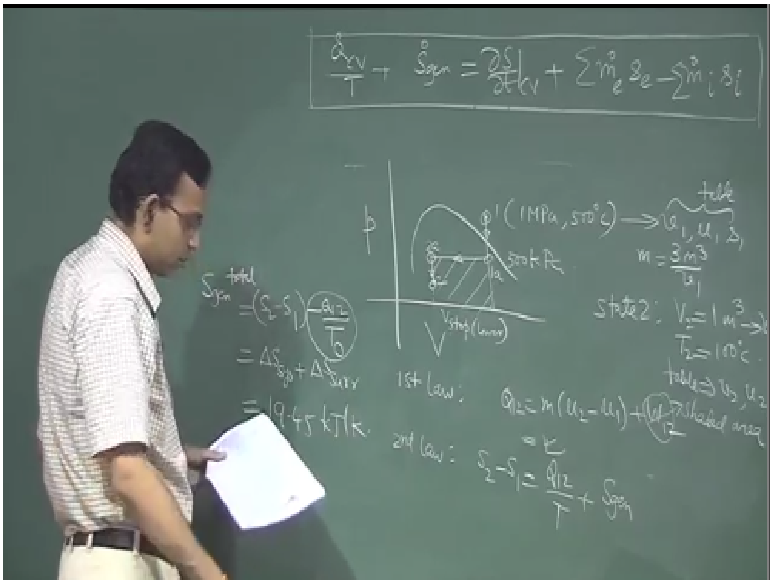

So at this volume now it cannot when a heat is continuously rejected its pressure will come down at constant volume so until it is cold until it becomes 100^0C, so state 2 how do you specify it V_2 = $1m^3$ and T_2 is let us call this 2a 100^0C. So this will tell you what is V_1 what is U_1 what is S1 all these you can get from table similarly if you know V_2 you know the mass how do you know the mass, mss is so instead one the volume is given which is $3m^3$ so m is $3m^3$ sorry V1 / 3 sorry $3m^3$/ V_1 so you can get V_2 as V_2 / m so from table you can get V_2 U_2 S_2 okay.

So now you apply the first law U_{12} = m x U_2 – U1 + W_{12} okay what is W_{12} is the area under this PV diagram okay this is the shaded area, so you get what us Q12 now second law S_2 – S_2 = Q_{12} / T + entropy generation, so this is the integral form of dS = δQ / T + dsJ if you integrate this, between states 1 and 2 so S_2 – S_1 is = Q_{12} / T + S_{jl} where is what T will substitute here and this is the golden question so it depends on entropy generation due to which effective 12 capture here if you want to capture the entropy generation due to internal irreversibility is only then this should be the temperature.

Of the boundary of the system but if you want to capture the entropy generation because of the net change in entropy if the system and the surroundings, the this should be the surrounding temperature so if this includes the effect of both external and internal irreversibility this should be the surrounding temperature, but if it includes the effect of only the internal irreversibility this should be the system boundary temperature. Now the problem that is asked it says that what the total entropy is generated in the process.

So it is the combination of internal entropy generation due to internal and external irreversibility so in that case Sj in total, is this 2 – S_1 – Q_{12} / T0 but T0 is the surrounding temperature, so this is sometimes written as ΔS system + ΔS surrounding it is just another way of looking into the same equation why this is ΔS surrounding because when heat Q_{12} is transferred from system to surrounding with respect to surrounding, it is a negative heat transfer whatever comes from surrounding to the system that means surrounding gets depilated of it.

So and for the surrounding we are considering it to be a such a lots thermal dissolver that for the change in entropy you can use ds = δQ / T so you can use that TDS relationship for the surrounding no matter whether it is irreversible for the system or not for the surrounding you can use the heat transferred divide by it is absolute temperature so this is the this becomes the ΔS of the surrounding so this is just another way of interpreting the same result and if you substitute it, it comes out to be 19.45kj/ k sorry k/ k okay.

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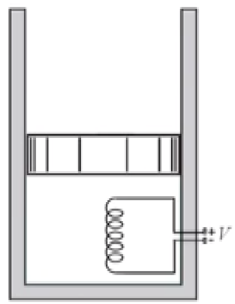
Problem 4.3: A vertical cylinder/piston contains R-22 at -20°C, 70 % quality and the volume is 50 litres, shown in the figure below. The cylinder is brought in a 20 °C room, and an electric current of 10 A is passed through the resistor inside the cylinder. The voltage drop across the resistor is 12 V. It is claimed that after 30 min the temperature inside the cylinder is 40 °C. Is this possible ?

Ans: Entropy generated = 0.768 kJ/K. It is possible



Next let us consider problem 4.3, so problem 4.3 there is a vertical cylinder piston this contains R-22 at -20^0 C, 70% quality and the volume is 50 liters as shown in the figure, the cylinder is brought in a 20^0 C room that means T0 is 20 + 273.15 so 293.15 Kelvin and an electric current of 10 ampere is passed though the registered inside the cylinder, so it is a very interesting problem where you also have electrical effect so this is something beyond the parading of simple compressible substance.

Where you also have electrical work associated the voltage drop across the register is 12 volt it is claimed that after 30 minute the temperature inside the cylinder is 40^0C and that increase in temperature is because of the Joule heating effect, so question is, is its possible? So the question that is asked is that is it possible is this claim possible, so whenever there is a question that comes that is any claim possible we have to assess the claim in the perspective of the first law and the second law.

So we have to see whether this claim violates first law and whether this claim violates second law, so typically we can create a situation when the claim will satisfy the first law but when the first law is satisfied we also have to guarantee that the second law also satisfied that means how do you know whether the second law is satisfied or not you calculate the entropy generation and show that it is positive.

If the entropy generation is positive that means it is a feasible process if the entropy generation comes out to be negative that means it is not a feasible process, so let us work out this problem so for the system which is the R-22.

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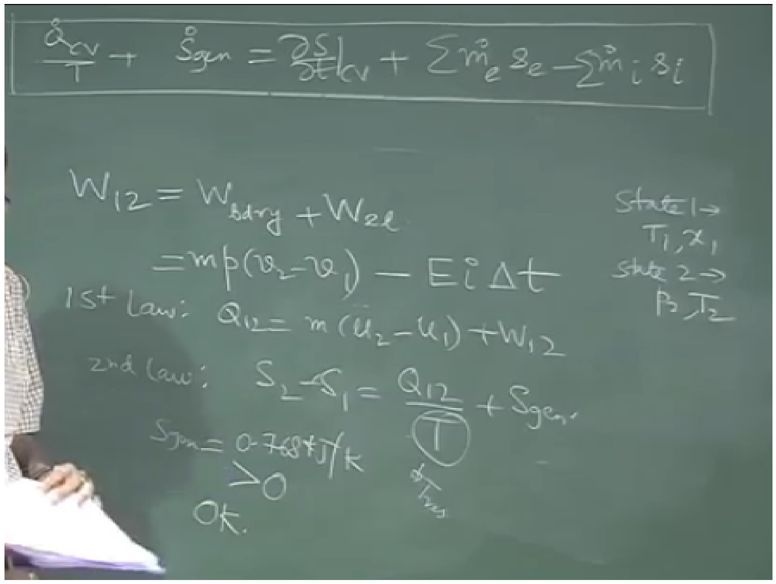

There are two types of work, one is this is problem 4.3 the work done is w moving boundary + w electrical, so what is the moving boundary work mp (v2 – v1) it is a constant pressure process if you look into the figure of the problem you will see that there is a piston which is floating and because the resistance pressure does not change the inside pressure also does not change as it is moving in a quasi- equilibrium process.

And what is the electrical work, the electrical work is minus the voltage into current into time this Δt is given as 30 minutes that is 30 x 60 seconds so now the first law you can apply Q_{12} = m(u2 – u1) = w_{12} and the second law s2 – s1 = Q_{12} /T + S_{jn} so this T you can put the temperature of the thermal reservoir which is 293.15 Kelvin, the reservoir is the room temperature which is 20^0C so 293.15 Kelvin.

And the states are given state1 R-22 at -20^0C 70% quality, so from the table of R-22 you can identify state 1 you know internal energy entropy all these from the table and state 2 the temperature is 40^0C and the pressure at state 2 is same as pressure at state 1, how do you know the pressure at state 1, pressure at state 1 is the saturation pressure corresponding to -20^0C because it is inductive two phase region.

Saturation temperature of ammonia, so the pressure at state 2 will be same as the pressure at state 1 which is P_{sat} (ammonia at -20^0C) from ammonia table, so state 1 is identified by T1 and X1 state 2 is identified by P2 and T2, so you know all the properties and you can calculate the entropy generation so if you calculate the entropy generation it becomes 0.768 kilo joule /Kelvin so this is greater than 0 that means this process is feasible, okay. So let us work out the next problem that is problem number 4.4.

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Problem 4.4: A rigid container with volume 200 L is divided into two equal volumes by a partition. Both sides contain nitrogen; one side is at 2 MPa, 200°C, and the other is at 200 kPa, 100°C. The partition ruptures, and the nitrogen comes to a uniform state at 70°C. Assuming the surroundings are at 20°C, find the work done and the net entropy change of the process.

Ans: Work Done = 0, Net entropy change = 0.2947 kJ/K

There is a rigid container with a volume of 200 liter it is divided into two equal volumes by a partition, both sides contain nitrogen one side at 2MPa, 200^0C another side as 200Kpa 100^0C, so the situation is like this.

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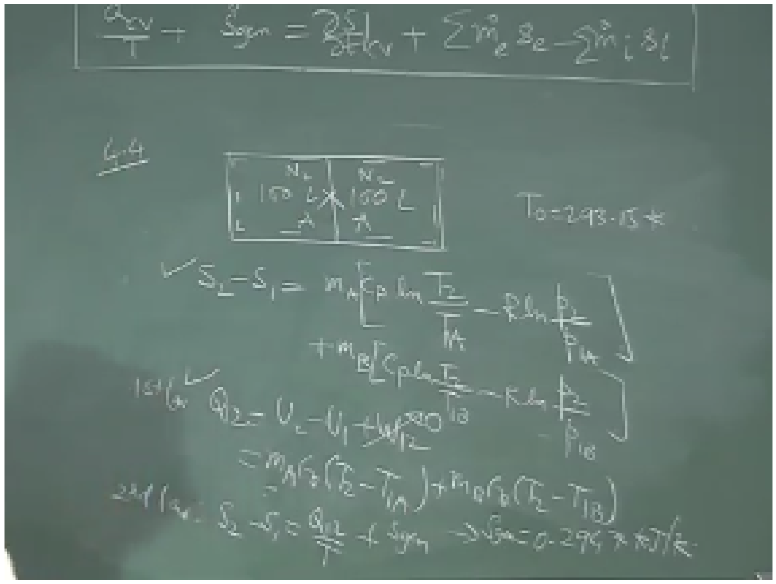

Problem 4.4, so there is a rigid container with the volume of 200L it is divided in to 2 equal portions both contain nitrogen the patrician raptures and the nitrogen comes to a uniform state. And the surroundings are 20^0 C that is 293.15K.

What is the, what done a net entropy change during the process, so to calculate the net entropy change during the process we can consider that the nitrogen is an ideal gas so you can calculate the change in entropy of the system. This is the change for a so using by integrating the TDS relationship for an ideal gas with constant cp and cv yu get s2 – s1 = cp ln t2/ t1 – Rln p2 / p1 okay.

So this you can do by integrating TDS = Dh – VDP for an ideal gas with constants cp and cv. So this is for A and this is for B, now what is the heat transfer ion the process? There is no watt done so the watt done is 0. Why there is not watt done? Because your control mass system is this one and that does not change in volume. So u2 – u1 is Ma (cv x t2 – t1 a) + Mb cv (t2 – t1B) and you can use the second law s2 – s1 = q12 / t where you can substitute t =\ t0 to get the entropy generation.

So s2 – s1 you can use form this formula q1 to use this from this formula and if you substitute this you will get the entropy generation which is 0.2947 kj/ k. so let us consider the next problem, problem 4.5 now this problem is a problem for flow process. Steam enters a turbine at 3MPa 450^0 C.

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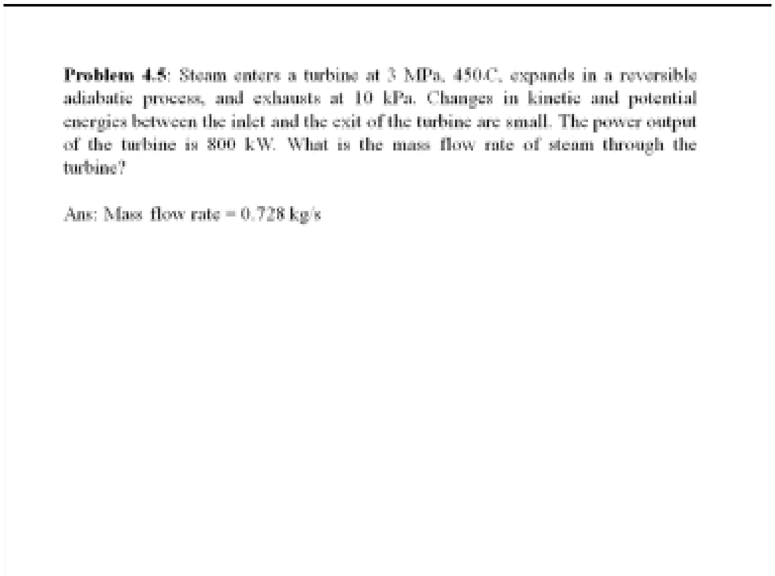

And expands in a reversible adiabatic process and exhaust at 10kPa, changes in kinetic energy and potential energy are small and power output of the turbine is 800 KW. What is the mass flow rate of steam through the turbine?

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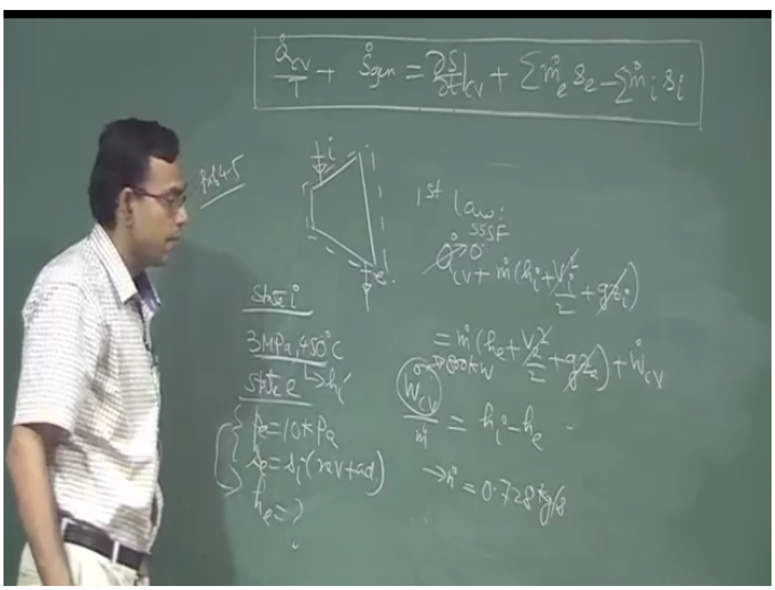

So in the turbine what happens let us write problem 4.5 so this is the schematic of a turbine normally we show the schematic with an expansion in the turbine conceptually shown by this expanded section. So this is I and this is e so first law Q^0cv so this is the steady state steady flow process and this is the control volume which is the turbine, so it is given that the process is adiabatic.

So this is 0 you neglect the changes in kinetic and potential energy that is also given so W^0cv/m^0 is equal to h_i-h_e so it is given that the rate of watt done by the power output of the turbine is 800kg watt so state I is given that the steam is at 3MPa 450^0 centigrade this is super heated steam 3MPa 450^0 centigrade.

The state e how do you specify state e the exit pressure is 10kPa and s_e=s_i because it is a reversible adiabatic so using this two from table you can calculate what is he you can find out what is he this will give what is hi so from here you can find out what is m^o this is 0.728kg per second next problem, problem number 4.6.

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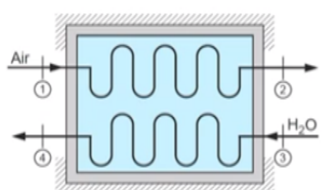
Problem 4.6: A counterflowing heat exchanger, as shown in the figure below, is used to cool air at 540 K, 400 kPa to 360 K by using a 0.05 kg/s supply of water at 20 °C, 200 kPa. The air flow is 0.5 kg/s in a 10-cm diameter pipe. Find the air inlet velocity, the water exit temperature and entropy generation in the process.

Ans: Total entropy generation = 0.02017 kW/K



You have a counter flow heat exchanger as shown in the figure so the heat exchanger is what it does it essentially uses the hot fluid to heat a cold fluid or it uses cold fluid to cool down a hot fluid so there is an exchange of heat between this two by the system if you look into the figure the system is insulated so that there is no let heat transfer between the system and the surrounding so if you draw this figure.

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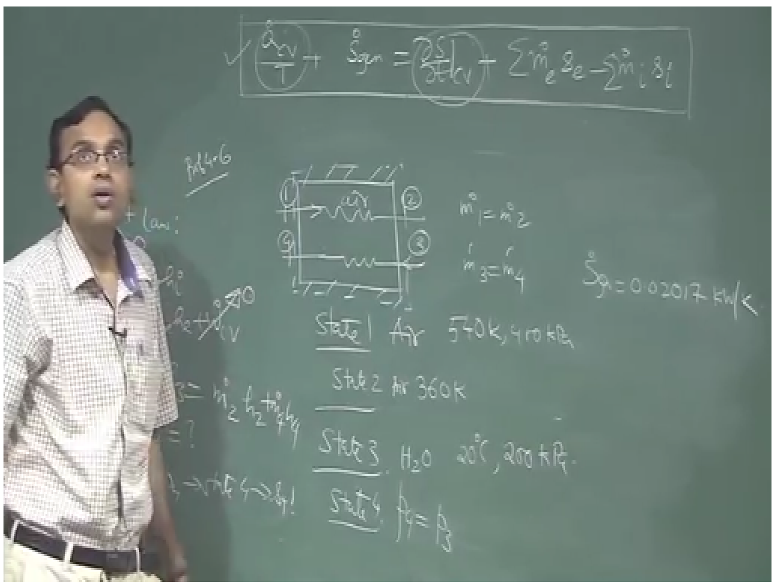

So there is air which enters the state one and leaves at state two and there is water which enters at state three and leaves at state four so it is so the water is used to cool the air so now we have identify the various states so state one so is 5040 Kelvin 400kPa so this two properties are there 540 Kelvin and 400kPa state two it is 360 Kelvin air.

If you assume ideal gas then the property will be function of temperature only okay then state three water state three is water at 20° centigrade 200 kilo Pascal and state four so assuming negligible pressure drop across this pipe line 3 to 4 you have P4= P3 and you have to calculate basically what is the other property that is needed to specify the state four.

So here control volume is the combination of the two streams this one so the first law let us write the first law in the second law $Q^0cv+£(m_oi$ hi neglecting changes in kinetic energy and potential energy there is no watt done there is no let het transfer so $m^o{}_i\ h_i$ is $m^o{}_1\ h_1+m^o{}_3\ h_3= m^o{}_2h_2+m^o{}_4\ h_4$and $m^o{}_1$ is same as $m^o{}_2$ and $m^o{}_3$ is same as mo4 so from here you can calculate what is h4, an h4 and p4 will give state 4 and that will give what is entropy and state 4 specifically entropy.

So now to calculate the entropy generation in the process, you refer to this equation, it is a steady state steady flow process so this term is not there and there is no need of heat transfer across the boundary of the system because it is just heat exchange between two streams. So if you use this you will get what is the entropy generation for this system.

For here you can use the ideal gas property, for water you have to use stable, so this a very typical problem, there are two fluids, foe one you have to use ideal gas consideration for other you have to use the trim okay. So I am giving you the final answer, the total entropy generation is 0.02017 kw/kg the rate of entropy generation. We will work out couple of more problems quickly; the next problem is just a one liner, problem number 4.7.

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Problem 4.7: A small pump takes in water at 20 °C, 100 kPa and pumps it to 2.5 MPa at a flow rate of 100 kg/min. Find the required pump power input.

Ans: Pump power input = 4 kW

A small pump takes in water at 20^0 C 100 kPa and pumps it to 2.5 MP at a flow rate of 100kg/min; find the required pump power input? So the key word for this problem is that it is a small pump. When it is small pump what it, means? When it is small pump it, means you may neglect the losses and you may assume it to be a reversible pump, reversible pump with single inlet and outlet.

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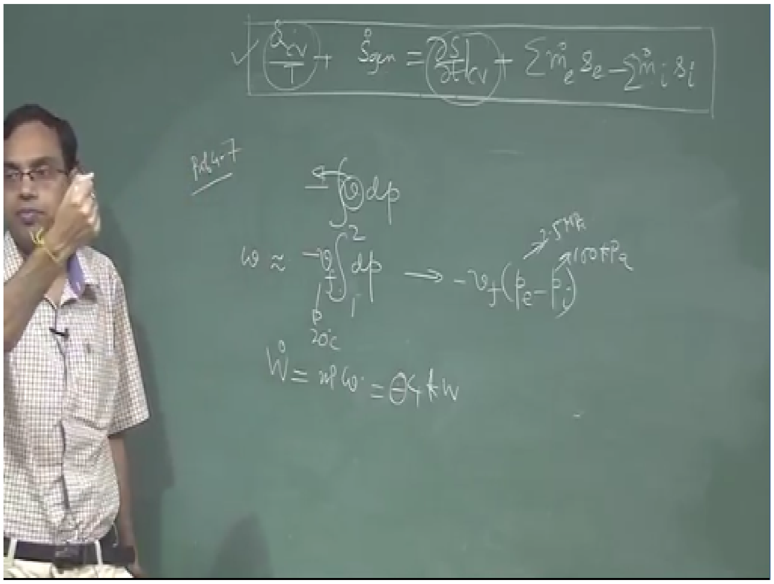

The work done is $-\int$ cdp if you neglect the changes in kinetic energy and potential energy, you recall that for a steady state, steady state flow process with at the reversible consideration and single inlet and single outlet this is the work done, if you neglect the changes in kinetic energy and potential energy. That pump is handling the liquid for which is v is the constant, so you can take this out of the integral and this is approximately = - vf x dp, vf at 2 20^0 C, so this is – vf x P2 – Pi, so this is 100kPa and this is 2.5 mp. So the total work done, so this is small w w. m. where m. is the mass slow rate 100kg/min, you have to convert kg/sec.

So this – 4 kw -4 means – means you have to energizes the pump, you have to waltz the pump to run the flow, so we can see here we have seen two example one is the energy producing the device and another consuming the device. The work producing device rather work producing and work consuming energy producing is not the correct terminology here, so the work producing device is the turbine and work consuming device is the pump and these two examples have already covered. The last example we will consider.

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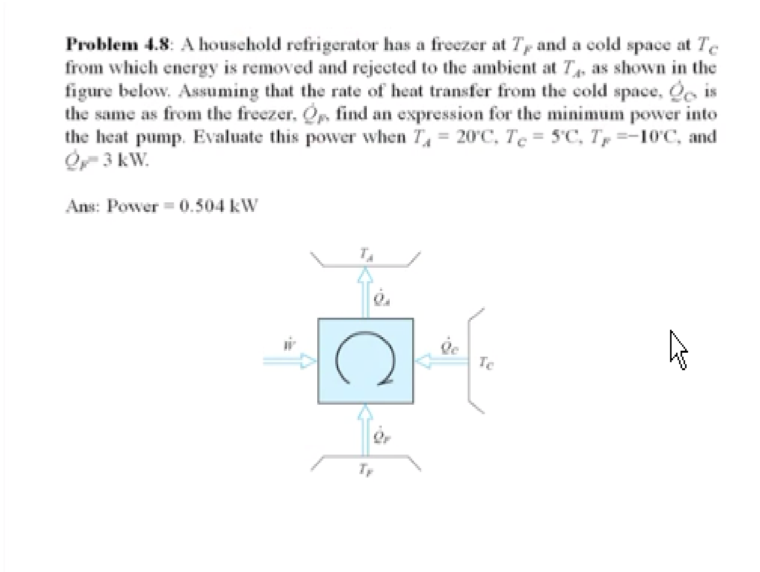

In this tutorial session this is problem number 4.8 which is projected on the screen.

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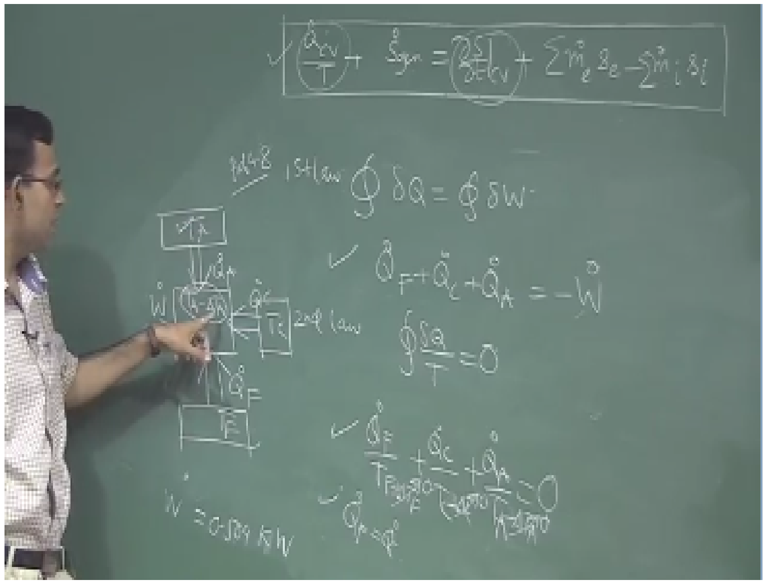

So you have a household refrigerator which has a freezer at TF and a cold space at TC at you see that this refrigerator takes heat Q.c from the whole space and Q.f from the freezer and it rejects the heat from Q.a m end, because it is a refrigerator it can operate in a cycle while transferring the heat from the lower temperature body to higher temperature body only if it does the work input and the work input in the figure you see the work input is w.

You have to find out the what is the minimum work input for the pump, for the refrigerator, so the minimum work input will be there only if it is reversible process because if it is not a reversible cycle, if it is the work consuming device it will consume more work because of loses, so we have to assume the reversible process. So if it is a reversible process, so first of all you will use for the cyclic process, cyclic ∫ of heat = cyclic integral of what? That is Goss law, so see this problem; we will solve the problem from the fundamental.

So cyclic integral of heat is Q.f + Q.c + Q.a in terms rate equation if we write and the cyclic integral of waltz is – w. that actual integral is the rate times the time but times get cancelled on both sides. So why – because it is the watt observing cyclic device it is not a work producing device and the second law because it is reversible cycle you have the cyclic integral l of the δ Q/T=0 ,so that means Q.F / T F = Q. C /T C +Q. A /TA that is =o. So look at this figure now.

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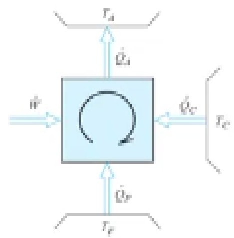
Problem 4.8: A household refrigerator has a freezer at T_F and a cold space at T_C from which energy is removed and rejected to the ambient at T_A, as shown in the figure below. Assuming that the rate of heat transfer from the cold space, $\dot{Q}_C$, is the same as from the freezer, $\dot{Q}_F$, find an expression for the minimum power into the heat pump. Evaluate this power when T_A = 20°C, T_C = 5°C, T_F =−10°C, and $\dot{Q}_F$= 3 kW.

Ans: Power = 0.504 kW



I am just trying to going to explain which is very important when you write the cyclic integral of the δ Q / T you are writing Q. A but the temperature here what I am showing in the mouse but actually it is the temperature here which is temperature at the system boundary but because we are considering in the externally reversible process that is the temperature difference between the system boundary and this one is consider with the very small but this is the T A this is T^ A +δ T A So this is as good as T A.

So we can write here that this is a T AS +δ T A this is T C +δ T C and this is the T A +δ T F okay, so there is a little bit of the problem with the figure may be that this is the sign of Q . A way is not shown correctly in the figure that is displayed here I have watch out this problem with this with this direction of the Q. A Q .C and Q. F so please contact the figure that his directions given in the board so this is the heat transfer to the system that is why I am consider as the both as the positive all as the positive okay this is T A and this T C and this T F.

So here because this is T A and this should be actually and this actually _δ T A not +if that is according to the diagram and it is the Q direction and it should opposite and T A +δ T A and here according to these diagram what I have shown here if this is T A this should be T A – δ T because this is smaller than the heat transfer is taking place so we are considering al amount the stories we are considering the temperatures a system already in the heat transfer is taking place okay.

Because this is ending to 0 this is the reversible process that is why we write this and what additionally formation is given is that the Q. F = Q .C so by combining this is equation and this equation you can find out the W. and answer is 0.504kilowatt okay so what we are apply basically is the first law of the cycle second law of the reversible cycle we have shown that the correct of the direction and the heat transfer and the watt done by considering the adiabatic sign and we have consider and the temperature of the system boundary.

But because it is externally reversible in the temperature differences is small so we have consider only the thermal reservoir temperature here so this completes the present tutorial and in the next section you have the review section and we will discussed about and the various concept and direct to the outstanding of the entropy and that will be take up in the next section thank you very much.